

COMPARISON OF CLINICAL AND DIGITAL RADIOGRAPHIC DETECTION OF OCCLUSAL AND PROXIMAL DENTAL CARIES IN CARIES-ACTIVE ADULTS

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ABSTRACT

Mario D. Ramos: Comparison of clinical and digital radiographic detection of occlusal and proximal dental caries in caries-active adults.
(Under the direction of Dr. André V. Ritter)

Radiographs have been shown to be an important adjunct to visual-tactile caries exams, but its contribution to a caries examination in caries-active adults has not been fully determined. Aims: to determine the extent of the agreement between a clinical examination (CE) and a radiographic examination (RE) in detecting presumptive caries lesions on occlusal and proximal surfaces of posterior teeth of participants enrolled in the UNC arm of the Xylitol for Adult Caries Trial (X-ACT); and to determine the additional caries diagnostic yield on occlusal and proximal surfaces of posterior teeth for those participants. Materials and methods: Baseline dental CE data from participants (21-80 years old) enrolled in the UNC arm of the X-ACT study site were used. Participants had a complete set of interproximal radiographs obtained within 7 months of the date of the CE (n=114). After IRB approval, radiographs of proximal and occlusal surfaces of the posterior teeth were assessed independently by two examiners on 114 participants' records (442 bitewings). The raw data for this study therefore consisted of surface-level clinical and radiographic scores coded as disease, non-disease, or missing. Descriptive statistics were obtained for all surfaces and by surface type (occlusal vs. proximal). Kappa statistics were used as an estimate of agreement between the clinical and the radiographic exams. The data were analyzed using Microsoft Excel 2007 and SAS. Results: A total of 2415 surfaces were examined by both CE and RE (722 occlusal and 1693 proximal surfaces). There were 1233 (34%) surfaces considered missing. Among all surfaces combined, Kappa between CE and RE was 0.18. When occlusal and proximal surfaces were analyzed separately, the Kappa between CE and RE were 0.04 and 0.18, respectively. The additional diagnostic yield by RE over CE was 69.2% for all surfaces combined, (54.6% for occlusal surfaces, and 71.0% for proximal surfaces). Conclusions: There is poor agreement between a CE and RE when used to detect caries in posterior teeth of caries-active adults. However, a radiographic caries exam performed within

7 months of the date of the clinical exam adds substantial diagnostic yield to the clinical exam, especially on proximal surfaces.

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INTRODUCTION

Visual-tactile inspection is the most commonly used dental caries detection method in clinical practice, epidemiological studies, and in caries clinical trials.¹ This method focuses on finding clinical signs of caries such as cavitation, fissure discoloration and enamel decalcification.² Radiographic examinations are routinely used in conjunction with visual-tactile inspection, because radiographs can provide additional information about the status of occlusal and interproximal surfaces.

The diagnostic accuracy of radiographs for occlusal caries varies with lesion depth and clinical presentation.^{1,3} Several studies have demonstrated that radiographs are useful in detecting particularly large dentinal lesions.³⁻⁵ However, because lesions in occlusal surfaces with a clinically visible breakdown often penetrate into dentin,³ such surfaces will hardly need radiographs to confirm the diagnosis. In contrast, clinically “sound” and apparently intact occlusal surfaces may also present lesions which penetrate into the dentin.⁶ Radiography may reveal dentinal occlusal lesions in apparently intact occlusal surfaces with no clinical signs of caries activity.⁶⁻⁹ Weerheijm⁹ and colleagues showed significantly more occlusal radiolucencies on bitewing radiographs than clinically recorded dentin lesions. Similar results were presented by Sawle et al.¹⁰ and Creanor et al.⁴

Proximal caries can also be challenging to detect clinically,^{7,8,11} especially early proximal caries lesions. Radiographs are routinely used to detect interproximal caries. Kidd and Pitts reported that the use of bitewing radiographs, as an aid to clinical diagnosis, is essential if much proximal caries is not to be missed.¹² Using traditional clinical caries detection criteria, it is accepted that a bitewing radiograph provides significant diagnostic yield for proximal^{8,11,13,14} (and occlusal) lesions detected by a visual-tactile exam alone.^{3,7-9} Studies show a significant underestimation of proximal caries when clinical data is compared with radiological findings.^{7,15-17} For example, using the WHO system of classifying lesions clinically at the cavitation level (DMFS and DMFT) with a radiographic criteria derived from the same clinical protocol, Poorterman and collaborators found that from the total of recorded decayed or inadequately restored surfaces only 10.8% and 13.8% were found clinically,

concluding that the prevalence of proximal caries and inadequate restorations was underestimated with visual-tactile examination alone.¹⁸ In addition, a comparison of epidemiological examinations employing different combinations of diagnostic tools found that using a combination of clinical and radiographic detection methods produces more accurate results.⁷

The vast majority of reports comparing clinical vs. radiographic caries exams are based on traditional clinical caries classification methods, such as the WHO criteria (DMFT, DMFS), where only cavitated and restored lesions are classified as disease and contribute to prevalence and incidence estimates.¹⁹ These traditional methods do not include non-cavitated or early lesions in measures of disease frequency.¹⁹ Additionally, the reliability and reproducibility of currently available caries detection/diagnostic methods, including visual and visual-tactile criteria, are not strong.²⁰ In response to the growing interest in the detection and management of early lesions, the International Caries Detection and Assessment System (ICDAS) was developed.^{19,21} The ICDAS is a standardized clinical scoring system for caries detection that includes cavitated and non-cavitated lesions.^{19,22-25} The system has been tested for reproducibility and accuracy in detecting occlusal and proximal caries lesions in different stages of disease^{19,22,23,25} Additionally, there are efforts to produce criteria for root caries.²⁶⁻²⁸

However, there are only a few brief reports on the comparison of the ICDAS clinical caries scoring system with radiography for caries detection.^{29,30} Eggertsson and collaborators reported their findings based on 35187 proximal surfaces of children between 6 and 15 years old for whom a visual-tactile clinical caries exam using ICDAS I and digital bitewing radiographs were performed separately.²⁹ Without specifying about the use of a histological validation, their results showed a roughly two-fold increase in caries levels detected when comparing visual detection (9.3%) versus radiographic detection (16.3%). Both methods identified the majority of the caries lesions as being on enamel (96.5% with ICDAS and 85% with the radiographic assessment). Radiographs allowed the identification of 12.2% of the dentin lesions, whereas the visual detection ICDAS system found only 3.5%.

Similarly, Cortes and colleagues reported their findings of comparison between the ICDAS II system, fiber optic transillumination, and bitewing radiography for caries detection on occlusal and proximal surfaces on 61 children between 8 and 14 years old.³⁰ Visual detection by itself detected more lesions on enamel (4.8% on proximal surfaces and 18% on

occlusal surfaces) than radiography (2.1% on proximal surfaces and none on occlusal surfaces). However for the detection of dentinal caries, the findings were different: 1.7% and 2.0% for proximal surfaces, 6.3% and 9.3% for occlusal surfaces, when comparing the visual detection and the radiography method respectively.

Elkstrand and colleagues³¹ have tried to correlate the severity of caries lesions with their histological depth. They found that white spot lesions which require air-drying are most likely to be limited to the outer ½ of the enamel. The depth of a white or brown spot lesion which is evident without air drying is located between the inner ½ of the enamel and the outer 1/2 of the dentin. In cases of a localized enamel cavitation due to caries with no visible dentin, or a greyish, brownish or bluish shadow of the dentin shining up through apparently non-cavitated enamel, both indicate that the lesion extends somewhere between the outer and inner ½ of dentin. Frank cavities with visible dentin indicate that a lesion has been extended to inner ½ of the dentin. On 2007, Elkstrand and colleagues²² using their findings from 1995 for crosstabulation, investigated the relationship between ICDAS's seven-point classification system when applied to the occlusal, free smooth and proximal surfaces of extracted posterior teeth. The results using ICDAS I showed a strong relationship between clinical caries and histological caries for occlusal, free smooth and proximal surfaces (Spearman correlation coefficients = 0.93, 0.95 and 0.94 respectively). Similarly for the second examiner the correlation coefficients were 0.87, 0.96 and 0.92 respectively.

Studies that compared the performance of clinical and radiographic caries detection methods on adults (Table 1 and 2)^{7,9,13,17,18,29,32-37} show a poor agreement, a large variation in methodology such as incomplete descriptions of selection and diagnostic criteria, a marked difference on caries lesions prevalence and a tendency to use young adults. Additionally, there is a paucity of information relating to adults, the elderly and groups with high caries prevalence. Due to similar patterns of caries prevalence and predisposing factors, the information obtained from children has been extrapolated to adults,³⁸ however investigators must be encouraged to contribute with in vivo studies that fill the existing gaps, build upon existing findings and use methodology that contribute to the comparison between studies.²⁰ The National Institutes of Health Consensus Development Conference on Diagnosis and Management of Dental Caries Throughout Life recommended additional caries trials in adults.³⁹

There are few studies with the aim to compare the agreement between clinical (CE) and radiographic (RE) caries detection methods on adults. In 2007, Galcera-Civera and colleagues³² compared CE with digital RE and among occlusal and proximal surfaces in the posterior teeth on a group of patients with low caries prevalence utilizing linear weighted Kappa as a measure of agreement. They found a poor agreement between CE and RE among all surfaces (Kappa=0.17), occlusal (Kappa=0.28) and proximal (Kappa=0.18) surfaces. However, when evaluating the additional diagnostic yield (the additional lesions detected by RE alone as a percentage of all the lesions detected by CE), it was found that 3.23 times more caries lesions were detected with digital radiography than by visual examination. They concluded that the use of radiographic methods increase the number of caries lesions detected in comparison with CE.

There is little evidence concerning diagnostic yield of bitewing radiography for caries in adults. In general, the caries process progresses slowly, but lifestyle changes can have a significant impact on the caries incidence.³⁸ In recent years, there has been a decline of caries prevalence among children and young adults⁴⁰ which has been attributed to fluoride exposure.¹⁸ These make it unlikely that a single detection method will have the adequate sensitivity and specificity to detect caries at all sites. The addition of a radiographic caries detection method to a clinical caries detection method would increase the overall efficacy and precision of caries detection.

In light of the above, the purposes of this study were to determine the extent of the agreement between CE and RE in identifying presumptive caries lesions on occlusal and proximal surfaces of posterior teeth of participants enrolled in the Xylitol for Adult Caries Trial (X-ACT), and to determine the additional caries diagnostic yield on occlusal and proximal surfaces obtained by supplementing CE findings with RE findings for those same participants.

It is important to note that neither the X-ACT trial nor the current study used a gold standard for caries lesion presence, which would require histological verification of the presence/absence of cavitation and the extent of the demineralization/bacterial invasion (caries lesion). All caries lesions detected by either the CE, the RE, or both, should, therefore, be considered presumptive caries lesions.

SPECIFIC AIMS

Specific Aim 1: to determine the extent of the agreement between a clinical caries exam and a radiographic caries exam in detecting presumptive caries lesions on occlusal and proximal surfaces of posterior teeth of participants enrolled in the Xylitol for Adult Caries Trial (X-ACT); and

Specific Aim 2: to determine the additional caries diagnostic yield on occlusal and proximal surfaces of posterior teeth obtained by supplementing CE findings with RE findings of participants enrolled in the X-ACT.

METHODS

Population/Sample

The sample for this study (N=239) consisted of subjects who participated in the X-ACT trial at the University of North Carolina at Chapel Hill (UNC). Study participants were recruited from the UNC dental school clinics. To be eligible, participants had to be aged 21-80 years, had at least 12 teeth with exposed dental surfaces, and had one or more coronal or root caries lesions either at time of the baseline examination or documented within the 12 months prior to the baseline examination.

Candidates were excluded if they had more than ten teeth with caries lesions, a history of head and neck radiation cancer therapy, or were receiving long-term antibiotic therapy. Anyone with known allergy to xylitol or other mint component, serious illnesses, dietary restrictions, or those planning to leave the catchment area prior to the end of the study were also excluded.

This study was approved by the X-ACT Steering Committee, and both this study and the X-ACT trial were approved by the the UNC Biomedical IRB.

Clinical measures

The clinical visual-tactile data for this study were obtained from the baseline clinical caries exams (CE) data available from X-ACT data files. The X-ACT clinical data collection will be briefly described. A trained and calibrated examiner performed a baseline oral exam on all the existing permanent (anterior and posterior) teeth and supporting tissues for each participant in a standard dental operatory equipped with dental light and air-water syringe. The examiner used a dental mirror and a Community Periodontal Index of Treatment Needs (CPITN) dental probe for the exams as well as magnifying loupes. With the help of a trained study recorder, the examiner recorded coronal and root surfaces missing, sound, carious, restored, or sealed, as well as surfaces that were unable to be scored (Table 3, Clinical Criteria). Restored and sealed surfaces with caries were also recorded as such. The caries classification system used for the clinical exams was a modification of the International Caries Detection and Assessment System (ICDAS II),⁴¹ summarized in Table 3.

The clinical caries exam data were tabulated so that for each subject a code was entered for each occlusal and proximal surface of each non-missing posterior tooth.

Radiographic measures

Most subjects in the UNC sub-sample of the X-ACT trial were patients of record in the dental school clinics and as such have a unique password-protected electronic patient record (EPR). Data from digital radiographic images for this study (radiographic exam, RE) were obtained from the participants' records. No new radiographs were obtained for this study. Only data from participants who had a set of interproximal radiographs (horizontal bitewings) obtained within 7 months of the date of the baseline caries exam were used. Based on the records of 239 subjects, the radiographic data for 114 participants and a total of 442 bitewing radiographs were found. It was expected the existing radiographs to be well standardized, as they were all obtained and processed in the same dental school environment, following standardized protocols, similarly trained personnel, and similar equipment.

Because of its correlation with the ICDAS II classification system, a modification of the criteria proposed by Pitts⁴² for coronal caries was used to score proximal and occlusal surfaces (Table 3). Root surfaces were not included on the radiographic data because there is a very limited number of studies²⁰ among its detection performance that satisfy histological validation, professional application and reports on comparative clinical studies;⁴³ and there is insufficient evidence available supporting the use of radiographs as caries detection methods for root caries.⁴³

Study procedures

The CE caries data were already collected and available for use. This section therefore describes the procedures used to obtain the RE caries data.

Two examiners (MR and FA) with 6 and 14 years of clinical experience respectively were trained in caries detection and caries depth assessment in a 2-hour session using a standardized set of digital radiographic images used in a UNC Introduction to Dental Radiology course (Fig. 1). The training also included a 1-hour lecture on the radiographic criteria used in the study (Table 3). The details of each score from the radiographic caries detection method with its corresponding radiographic images (occlusal and proximal

surfaces) were discussed. The purposes of these training sessions were to familiarize the examiners with the radiographic criteria used in the study, to train the examiners on the use of the radiographic caries detection method, and to make the examiners proficient in detecting coronal caries radiographically. Agreement of 75% or more during the calibration session in detecting coronal caries radiographically was the adequate level of proficiency.

After completing the training sessions, the examiners started the calibration session. Four different sub-sets of 20 bitewing radiographs not used in the main data collection phase were obtained from the study participants to assess reliability between examiners. Such radiographic images were out of the time frame and were not intended to be used for the main project. The inter-examiner agreement was calculated between both examiners with Kappa scores of 0.70, 0.78, 0.80 and 0.87 for the different sub-sets. Such values were considered on the range of good to excellent.⁹

To establish the intra-examiner agreement 2 different sets of 20 radiographs were analyzed independently by both examiners. The Kappa values were 0.84 and 0.87. Such values were considered excellent.⁹

Once the training and calibration sessions were completed, the evaluation of all the participants' bitewing radiographs started. The same examiners independently assessed only the horizontal bitewing radiographs that were exposed within 7 months of the CE of all participants. The occlusal and proximal surfaces of the posterior teeth, from the distal surface of the first premolar to the mesial surface of the second molar in each quadrant were examined based on the described radiographic criteria. In case of uncertainty on the evaluation between two different bitewing radiographs of the same tooth, firstly the bitewing radiograph with the better resolution was used; if it was not obvious which image had better resolution, both images were evaluated, and a lesion on either image was considered a lesion.

During all the phases of the project, the radiographic images were examined using two 15.4'' Lenovo computers (Cary, NC, USA) with similar resolution settings using the image enhancement tools (such as density adjustment, contrast, gamma curve and magnification)⁴⁴ on the EPR system, as pleased, in a dark room.

The data was recorded in independent forms for each participant (Appendix)

Data analyses

These analyses only include data obtained from CE and RE from occlusal and proximal surfaces of the posterior teeth, as described previously. The rationale behind the inclusion of only posterior teeth on the present study is the lack of anterior bitewing radiographs on the patient's record system. In order to simplify the analyses for the purposes of this thesis, all data was recoded as a dichotomous measure of non-disease vs. disease. The clinical data were recoded as non-disease (score 0) for the codes S, F, C and P, and caries events or disease (score 1) for the codes D1, D2, D3, FD1, FD2, FD3, PD1, PD2, PD3, CD1, CD2, and CD3. The radiographic recordings were recoded as non-disease (score 0) for codes 0, F and C whereas caries events or disease (score 1) for the codes 1, F1, C1, 2, F2, C2, 3, F3, C3, 4, F4 and C4 (Table 4). Additionally, data was considered missing (M) when surfaces were coded as Y and/or M on either one or both examinations, or when there were mismatches on the data between the clinical and the radiographic exam due to the changes on surface status that occurred over the period between the examinations (Table 4).

Of the total of 3648 occlusal and proximal surfaces (442 bitewing images) in 114 participants, a total of 1233 (34%) surfaces were considered missing (M). Therefore, a total of 2415 surfaces (722 occlusal and 1693 proximal) were included in the analyses. The method of recording and calculating the amount of caries lesions detected by each method utilized in this study was based on Kidd and Pitts' metaanalysis.¹² (Fig. 2) In the present study four variables were calculated:

- (A) The number of caries lesions detected exclusively by CE.
- (B) The number of caries lesions detected exclusively by RE.
- (C) The number of caries lesions common to both examinations.
- (T) The total number of caries lesions detected.

To determine the additional diagnostic yield (Aim 2) on occlusal and proximal surfaces obtained by supplementing CE findings with RE findings, additional calculations were made:

- (1) The total number of caries lesions detected by CE: $A+C$.
- (2) The total number of caries lesions detected by RE: $B+C$.
- (3) The additional diagnostic yield: The additional caries lesions detected by RE alone as a percentage of all the caries lesions detected by CE: $B/(A+C) \times 100/1$.

Statistical analysis

Descriptive statistics (frequencies and percentages) and proportions were obtained from all surfaces and by type of surface, using Microsoft Excel 2007 (Redmond, WA, USA). For aim 1, the extent of agreement between CE and RE beyond chance alone was analyzed using Kappa statistics. The test was adjusted at 95% confidence intervals. For aim 2, the additional diagnostic yield was calculated manually. Data were analyzed using Microsoft Excel 2007 (Redmond, WA, USA) and SAS (Cary, NC, USA)

RESULTS

Results from Aim 1, the extent of the agreement between CE and RE in identifying presumptive caries lesions on occlusal and proximal surfaces of posterior teeth, are presented in Table 5. There was poor agreement between CE and RE ($\text{Kappa}=0.18$). A total of 494 surfaces were detected as diseased by one or both detection methods among all surfaces. CE detected disease on 292 (59.1%) of these surfaces, whereas RE detected disease on 283 (57.3%) of these surfaces. Additionally, the total raw percentage agreement between CE and RE was 82.9% (79.5% for non-disease and 3.4% for disease).

A site-specific comparison between CE and RE showed poor agreement ($\text{Kappa}=0.04$) for diseased occlusal surfaces. From a total of 51 surfaces detected as caries lesions by one or both detection methods, 33 (64.7%) and 20 (39.2%) surfaces were found to be diseased by CE and RE respectively. The raw percentage agreement for occlusal surfaces was 93.2% (92.9% for non-disease and 0.3% for disease).

The analysis for proximal surfaces shows a similar pattern of poor level of agreement between CE and RE ($\text{Kappa}=0.18$). CE found disease on 259 (58.5%) surfaces, while 263 (59.4%) diseased surfaces were found by RE. The total raw agreement between CE and RE methods for the assessment of proximal surfaces is 78.50% (73.8% for non-disease and 4.7% for disease).

Results from Aim 2, the additional caries diagnostic yield on occlusal and proximal surfaces obtained by supplementing CE findings with RE findings, are presented in Table 6. The diagnostic yield added by the RE was 69.2% among all surfaces. Additional yield was greater on proximal surfaces (71.0%) than on occlusal surfaces (54.6%).

DISCUSSION

There have been many papers comparing the discriminatory abilities of clinical and radiographic caries detection methods, however only few studies involved subjects over 20 years of age.^{12,17} According to the 2010 US Census Bureau, the adult population (18 years or older) constitute 76% of the entire United States of America population.⁴⁸

The detection of caries lesions assumes particular importance when it is appreciated that all lesions do not inevitably progress to cavitation. Lesion progression may be delayed, arrested or in early stages of the demineralization process stopped so that preventive treatment may be carried out.¹² The detection of caries lesions has been primarily a visual process, based principally on clinical inspection and review of radiographs.²⁰ The history of visual-tactile caries detection goes back to antiquity, however the criteria used, and the means and methods employed have changed over time.⁴⁹ However, with the introduction of bitewing radiography for caries detection, generations of dentists seem to have lost reliance on the classical visual-tactile caries detection method.⁴⁹ It is very important to realize that the later detection method serves as an aid to caries diagnosis and that there are limitations and benefits.

Data from various studies have shown the ICDAS criteria to be a reliable and effective tool for various applications.^{23,24,48} It has been successfully applied in in-vitro^{19,25} as well as clinical studies^{19,21,24,29,30} (validation study, secondary caries, epidemiology, study on caries risk factors and clinical trial), in different dentitions^{19,21,24,25,29,30} (primary and permanent teeth), in different age groups^{19,21,23,24,48} (children, teenagers, young adults and adults), and multiple examiners with different backgrounds as well as previous exposure and experience with the criteria.⁵⁰ However, few studies have been performed on proximal surfaces using ICDAS in adult populations. The ICDAS' interexaminer reproducibility on proximal surfaces has been similar to that observed for occlusal surfaces.^{51,52} These properties should encourage the use of ICDAS also in proximal caries detection, although other additional methods such as the radiographic method should be added to improve sensitivity on these surfaces.

Our postulated radiographic criteria based on the Pitts radiographic criteria,⁴² are similar to the clinical ICDAS-II criteria used for the clinical portion of the study. Even

though the radiographic criteria lack histological validation, they are accompanied by a detailed protocol of calibration by the examiners, which is desirable when proposing current caries diagnostic systems.⁵³ The reasons to develop a radiographic criteria would be to develop a systematic approach for epidemiological surveillance, produce an enhanced method applicable for practitioners, unify existing methods, and provide adequate systematic baselines to be compared in the time.

In the present study, despite having collected the entire data of the CE and the RE using different levels of caries lesion the data analysis from both detection methods was performed utilizing a dichotomous manner (disease and non-disease). Among the reasons behind the decision to collapse the data are that ICDAS clinical caries detection criteria measures the surface changes and potential histological depth of caries lesions by relying on surface characteristics, the disparity between the severity of caries lesions with its histological depth as shown by Elkstrand and colleagues,³¹ and the potential of the non-cavitated caries lesions to progress to deeper caries lesions in the future.

In the present study, Kappa statistics were used to determine the extent of the agreement between CE and RE in identifying presumptive caries lesions on occlusal and proximal surfaces of posterior teeth on participants enrolled in the Xylitol for Adult Caries Trial (X-ACT). Kappa values showed a poor level of agreement (Kappa=0.18) among all surfaces (specifically Kappa=0.04 for occlusal lesions and Kappa=0.18 for proximal lesions). However, the raw percentage agreement among all surfaces (82.9%), occlusal (93.2%) and proximal (78.5) surfaces showed relatively high levels of agreement probably due to chance alone, the result of the low prevalence of caries lesions on the population, and the corresponding large proportion of sound surfaces among all surfaces.

To compare our findings with those from other studies comparing CE with RE for caries detection, it was necessary to manage the data from other studies in two different ways: (1) when Kappa values were not reported, they were calculated, and (2) when additional diagnostic yield was not reported, it was calculated. Both calculations were performed in a consistent format proposed by Kidd and Pitts¹² (Table 1 and Table 2). However some studies precluded additional calculations due to their methodology or lack of information. Tables 1 and 2 show a summary of the results from available studies^{7,9,13,17,18,29,32-37} on adult populations comparing CE and RE caries detection methods

on occlusal and proximal surfaces of posterior teeth. A review of these papers showed that the literature is further limited due to a large variation in methodology such as incomplete descriptions of selection and diagnostic criteria, differences on caries lesions prevalence on the populations studied and a tendency to use young adults as a population of interest. Additionally there were large differences in sample sizes (ranging from 30 to 879 subjects), variable descriptions, missing data, non-participants rate and independence on the examinations. Ismail,⁵³ on a review on the content validity of 29 different clinical criteria methods for caries detection, concluded that there is a substantial variability in disease processes measured, inclusion and exclusion criteria, and examination conditions. Among all the previous studies, there are wide variations in the degree of standardization achieved, in the composition of the study groups and duration of the studies.

Regarding caries prevalence among adult population, the National Center for Chronic Disease Prevention and Health Promotion, stated that untreated tooth decay has decreased 5.1% from 27.9% to 22.7% from the period of 1988-1994 to 1999-2002 among United States of America population.⁴⁰

On evaluating the comparison between CE and RE in identifying presumptive caries lesions on occlusal surfaces of posterior teeth on adult populations, it was evident that there were few available comparative reports.^{7,32} Galcera-Civera and colleagues³², compare CE with digital RE among occlusal and proximal surfaces in the posterior teeth on a group of patients with low caries prevalence utilizing linear weighted Kappa as a measure of agreement. They found a poor agreement between CE and RE among occlusal (Kappa=0.28) but a high raw agreement (97.9%) surfaces. Similar results were extracted from the study by Hopcraft and colleagues⁷ on 2005. When the two methods (CE and RE) were compared, a Kappa=0.33 was found in conjunct to a percentage of agreement of 98.4%. Our results (Kappa=0.04 and percentage of agreement of 93.2%) show a poorer agreement between CE and RE in identifying caries lesions on occlusal surfaces of posterior teeth; however the raw agreement was very high (Table 1).

The present study show a poor agreement (Kappa=0.18) between CE and RE in identifying proximal caries lesions on an adult population. Similar results were reported by Galcera-Civera and colleagues³². They found a Kappa=0.18 and a percentage of agreement of 94.4%. It is important to point out that besides having a similar radiographic criteria than the

one used in this study, they collapse the data for comparison purposes matching the non-cavitated clinical lesion on enamel (C1) as sound (S) on their radiographic score. That decision might underestimate the caries prevalence among proximal surfaces, and probably preclude the incorporation of preventive measures to delay caries progression. Some other studies^{7,13,18} allow us for the calculation of the Cohen's Kappa values for comparative purposes. From Hopcraft et al⁷ it was obtained a Kappa value of 0.31 and a raw percentage agreement of 98.9%. Similar patterns were found by Pooterman and collaborators^{13,18} using DMFS, showed Kappa values of 0.22-0.36 (poor agreement) between CE and RE among adult patients (25-24 years old) when having dentin as the detection threshold for the clinical caries detection criteria¹⁸ and a Kappa value of 0.11 when utilizing enamel as the clinical detection threshold on young adults (17-23 years old).¹³ For both studies, the radiographic criteria was set at the enamel and dentin level. (Table 2)

With reference to the caries prevalence among occlusal caries lesions, our results differ from other studies^{7,9,17,29,32} on adult populations (Table 2). In most of the studies the radiographic prevalence (83.2-100.0%) was found to be higher than the clinical prevalence (20.2-33.2%); however our results showed 64.7% of the occlusal lesions were detected by CE, whereas the radiographic prevalence was of 39.2% (Table 5). Similar results were found by Hopcraft and Morgan⁷ in 2005 based on young adults from Australia using the DMFS system, whom reported a higher prevalence of occlusal lesions detected by CE (81.3%) than with their radiographic method (38.3%) on a low-caries prevalence population. The disparity on Hopcraft's results with other studies^{9,17,29,32} is probably because they set the radiographic detection method with a threshold at the dentin level, whereas their clinical method includes cavitated enamel and dentin caries lesions altogether on a low-risk population where it is possible that the declining on the radiographic prevalence might be accompanied by an increase proportion of non-cavitated lesions remaining confined to enamel.

The rate of occlusal caries that cannot be detected by CE alone is found by the difference of the values between the total number of caries lesions found and the number of lesions detected by the RE alone. The present findings suggest that a substantial number of occlusal caries lesions (35%) in the adult dentition would be missed if bitewing radiographs are not exposed. The rates of caries lesions not detected by the CE on permanent dentition among young adolescents and young adults have been reported to be around 4-50%.^{9,56}

In the present study, in spite of a poor agreement between CE and RE on identifying caries lesions among all surfaces, CE appears to have more detection ability than RE in terms of prevalence on occlusal surfaces. This could be attributed to the expertise of the examiner in recognizing caries lesions, the high relationship between ICDAS on occlusal surfaces and its histological counterpart,³¹ and the inherent ICDAS's ability to detect the first changes on dental surfaces because of caries development.²¹ It has been suggested that the declining caries prevalence described in several papers and on epidemiologic reports⁵⁷ has been attributed to fluoride supplementation.⁵⁸ It can be possible that the present cohort was exposed to various forms of fluoride supplements over the years.

Regarding the clinical and radiographic assessment of proximal surfaces among studies based on adult populations with no histological validation,^{13,18,32-37} Table 5 shows that RE alone consistently detected a higher number of caries lesions (83.2-98.0%) than those detected by CE alone (10.8-32.7%). These estimates appear to be at variance with the present study, where the percentage of lesions detected by the RE alone (59.4%) lightly surpasses the lesions detected by CE alone (58.5%) (Table 5). Such difference with other studies could be due to high variability between diagnostic criteria,⁵⁹ diagnostic threshold,¹² the method of CE,¹² the difference on caries prevalence on the population examined which could affect the clinical caries detection assessment,⁵⁷ good clinical examiner training, poor radiographic examiner training/performance, etc.

The prevalence of the presumptive occlusal and proximal caries lesions was underestimated on the basis of a CE alone. Almost 40% of the presumptive proximal caries lesions and 35% of the presumptive occlusal caries lesions were not detected by CE. This in contrast to previous studies which have concluded that in some populations, the omission of radiographs will not result in a substantial loss of information.^{16,54} Both studies were performed on children populations with low caries prevalence, using the clinical DMFS caries diagnosis system which diagnose lesions at the level of cavitation. By focusing on frank cavities only, the DMFS approach to caries diagnosis ignores the opportunity for non-operative interventions and therefore cannot be recommended in modern caries management.⁴⁹ Another limitations of the DMFS index are that it gives equal weight to missing, untreated decayed or well-restored teeth, cannot account for sealed teeth and its invalid when teeth have been lost for reasons other than caries.⁵⁵

Unfortunately, the radiographic findings do not always correspond to the actual state of disease. Some lesions are not detected (false-negative) while a number of sound surfaces are detected as caries lesions (false-positive). The present study does not permit the calculation of the number of false-positive and false-negative findings because of a lack of histological standard. However, it is estimated that with a 10% prevalence of proximal dentin caries and plausible values for sensitivity (60%) and specificity (96%)⁶⁰ these numbers of diagnostic errors are equal. However, it should bear on mind that false-positive and false-negative diagnoses influence individual treatment decisions.¹⁸

Some disadvantages are present and must be considered when making treatment decisions based on radiographic findings, mainly on proximal surfaces. First, radiographic images underestimate the actual lesion depth (measured histologically) and are unable to show accurately the early stages of enamel caries lesions.^{61,62} Another factor is that radiographs do not indicate caries lesion activity and they are not able to detect the presence of cavitations (cavities).⁶² Furthermore, this method is technique-sensitive and unavoidably exposes the patient to the hazards of ionizing radiation. In the present study, the use of digital radiography allowed us the use of computer facilities, such as image enhancement and processing of the images, and sending the images between colleagues.^{62,63}

As it was explained before, the simplified analysis of the data in our study encompasses the incorporation of any type of diseased surfaces as presence of disease and lack of disease as absence of disease (Table 3). This simplification could be problematic when assessing restorations with secondary caries. In a tooth surface with secondary caries, the adjacent tooth tissue can be considered in two planes: “outer lesion” and a “wall lesion”.⁵⁰ Both have different characteristic features being the outer lesion more easily detectable by CE. However, the wall lesion which may start on the wall of a cavity in the presence of leakage or micro-leakage can mostly be detected radiographically. The presence of wall lesions can increment the number of lesions detected associated to restorations by radiographic method which could be missed by CE.⁵⁰ Similar situation can be encountered with the presence of sealants on occlusal surfaces with caries lesions beneath margins of the restoration.⁵⁰ However after collapsing our clinical and radiographic data, the presence or absence of caries adjacent to restorations was recoded without differentiating between primary and secondary caries lesion.

Although secondary caries is histologically similar to primary caries⁶⁴ its features could cause certain diagnostic problems, including difficulties in the differentiation among restoration margin discrepancies (marginal integrity, discoloration of the tooth at restoration margin), secondary caries and residual caries.⁶⁵ Sharp probing for signs of secondary caries has all of the limitations and drawbacks associated with its use for primary caries detection. In addition, probing restorations can be misleading as a probe may become impacted in a margin discrepancy that is not in fact carious.⁶⁶

There were substantial missing data from our study, 34% (1233) of the surfaces were considered missed. The first source of missing data occurred because the RE did not provided useable data. Between the reasons is that not all bitewings could be properly assessed because of the presence of orthodontic devices, radiographic errors or overlapping surfaces. However, overlapping seems not to add substantial information on caries prevalence as exposed by Rimmer and Pitts,⁶⁷ who studied the prevalence of caries on overlapping surfaces by temporary separation on a juvenile population (5-15 years); and demonstrated that among all the overlapped surfaces, 81.8% of the mesial surfaces and 93.1% of the proximal surfaces were sound. Another source of missing data came from the comparison between the CE and RE; bitewing radiographs were taken within a 7-month period from the date of the CE, which created differences on the values depending on which examination was first.

On assessing differences among caries detection methods, it is of epidemiological, clinical and public interest to define the diagnostic threshold used. This is important because when the caries lesion is cavitated, is generally thought to require restorative care unless known to be arrested; whereas small lesions, clinically and radiographically, should be treated preventively with the aim of arresting lesion progression. The clinical caries detection method (ICDAS-II) assessed surfaces by visual changes on the surface and correlated this with the possible depth.⁵⁰ The radiographic caries detection method used in this study did assess the lesion in the same manner: by depth. However, the present sub-analysis presented the results on a dichotomous manner (disease/non disease) considering enamel and dentin surfaces as diseased and sound surfaces as non-diseased (However, there exist available radiographic data from our study for sub-analysis of exposing differences at the dentin level).

The importance of setting the radiographic caries detection method at the enamel and dentin level is emphasized by the work of Pietila⁶⁸ on children, because she showed there was very large percentage of additional lesions detected by bitewings at the dentin level which doubled when enamel radiolucencies were included. Stephen et al⁶⁹ in a large sample of children (13 years old), separated dentin from enamel radiolucencies and found an increment of 3.3 times on the number of lesions when both levels were considered. Thus, studies which ignore the enamel lesions may not only underestimate the caries prevalence of the group but may also fail to identify potential problems for the patients for the future.

The studies included on the comparison only examined occlusal and proximal surfaces, on which the greatest differences between RE and CE are expected to be found: occlusal surfaces are difficult to assess because of restorations and fissures, and proximal surfaces are difficult to examine visually, therefore when assessing the prevalence of caries in an adult population care should be taken.

It is important to note that neither the X-ACT clinical trial nor the current study used a histological validation for caries lesion presence. All caries lesions detected by either the CE, the RE, or both, should, therefore, be considered presumptive caries lesions. The diagnostic yield is produced by the relationship between the clinical and radiographic caries detection methods. The definition of diagnostic yield on this study-based on the review by Kidd and Pitts- is defined as the additional lesions detected by the RE alone expressed as a percentage of the total number of lesions detected by CE. The results from this study indicates that the prevalence of the presumptive caries lesions was underestimated given that the additional diagnostic yield provided by the RE was of 69% among all surfaces. Similar additional diagnostic yields when RE alone was added to a CE were found among occlusal surfaces (54.5%) and proximal surfaces (71.0%) (Table 6). Those results were in line with other studies where gold standard was not used.^{9,12,13,17,18,29,34-37}

Regarding the analysis of the additional diagnostic yield among different studies on adults on occlusal surfaces,^{7,9,17,29,32} it is evident from table 1 that most of the studies showed an additional diagnostic increment in the range of 201.1-394.0%; except for the study by Hopcraft and colleagues⁷ whom showed three times less additional diagnostic yield (23.0%) than our study. Using the DMFS system, they reported a higher prevalence of occlusal lesions detected by CE (81.3%) than with their radiographic method (38.3%) on a low-caries

prevalence population of young adults from Australia. The disparity on Hopscraft's results with other studies^{9,17,29,32} and ours, is probably because they set the radiographic detection method with a threshold at the dentin level, whereas their clinical method includes only cavitated enamel and dentin caries lesions altogether on a low-risk population where it is possible that the declining on the radiographic prevalence might be accompanied by an increase proportion of non-cavitated lesions remaining confined to enamel.

The estimates for the additional diagnostic yield among proximal surfaces on studies based on adults^{13,18,33-37} are presented in table 2. It is evident that the results of our study showed a considerable additional diagnostic yield (71.04%) when RE was added to a CE; however the comparable previous studies are on a superior order of 192.2-827%. Among the possible reasons of differences among studies could be the high variability between diagnostic threshold and the method of CE¹², diagnostic criteria used,⁵⁹ the difference on caries prevalence on the population examined which could affect the clinical caries detection assessment,⁵⁷ a poor examiner training with the RE method, a good examiner training on the CE method, etc.

The range of additional diagnostic yield found on this study (54.6%-71.0%) when compared with other studies seems to be moderate. One of the reasons could be the amount of missing data. It was evident that 34% (1233) of the surfaces were considered missed. The first source of missing data occurred because the RE did not provided useable data due to the presence of orthodontic devices, radiographic errors or overlapping surfaces. Another source of missing data could be found on the relationship between the date of the RE and the CE; bitewing radiographs were taken within a 7-month period from the date of the CE, which created differences on the values depending on which examination was first. Another source of difference between the additional diagnostic yields with other studies would be the data analysis used. In our study, despite having collected the entire data of the CE and RE using different levels of caries lesion; the data analysis from both detection methods was performed utilizing a dichotomous manner (disease and non-disease). Among the reasons behind the decision to collapse the data are that ICDAS clinical caries detection criteria measures the surface changes and potential histological depth of caries lesions by relying on surface characteristics, the disparity between the severity of caries lesions with its histological depth

as shown by Elkstrand and colleagues,³¹ and the potential of the non-cavitated caries lesions to progress to deeper caries lesions in the future.

The present study indicates that the level of agreement between CE and RE in identifying caries lesions among all surfaces is poor and is consistent among occlusal and proximal surfaces. However, the additional diagnostic yield when RE was added to CE increases the number of caries detected among all, occlusal and proximal surfaces.

CONCLUSIONS

Within the limitations of this study, it can be concluded that there is poor agreement between the two examination methods (clinical and radiographic) when used to detect caries in posterior teeth of caries-active adults. However, a radiographic caries exam performed within 7 months of the date of the clinical exam adds substantial diagnostic yield to the clinical exam, especially on proximal surfaces.

FUTURE STUDIES

1. Demonstrate in vitro validity and in vivo reliability of the radiographic caries detection criteria used in this study, which is based on Pitts' radiographic criteria from 1984.
2. Different stratification of the data: enamel and dentin levels, type of surface (mesial and distal surfaces), type of tooth (premolar versus molar), gender, ranges of age and presence/absence of fluoridated water on adult populations.
3. Evaluations of the factors that influence on the caries increment: gender, previous history of restorations, fluoride access, hygiene habits, socio-economic status, race, degree of literacy among participants.
4. The present study is based on a three-year, multi-center, placebo controlled, double-blind, randomized clinical trial that tests the effects of daily use of xylitol lozenges versus placebo lozenges on the prevention of adult caries.⁷⁰ A new set of radiograph images from the study population at the end of the clinical trial, would allow a radiographic comparison on terms of caries increment, and caries activity assessment among all surfaces and type of surfaces (occlusal and proximal).
5. Comparison between epidemiologically assessed caries incidence and practitioner's treatment recommendations. A previous study found a poor relationship.⁷¹
6. Development and validation of a root caries detection criteria and subsequent applicability.
7. Evaluation of the root caries radiographic detection criteria and comparison with gingival variables for risk indicator assessment.
8. Development of an online rigorous radiographic calibration method, with the aim to be used by other research groups or people.
9. Evaluation of the time frame between RE and CE and the reduction between them.

TABLES AND FIGURES

Table 1. Summary of studies investigating the value of bitewing radiographs in the diagnosis of occlusal caries in permanent teeth.

Study (year)	N	Age	Diagnostic threshold		Histologic validation	Lesions detected			Kappa value ¹	Percentage of agreement ²	Additional diagnostic yield (%)
			CE	RE		CE alone	RE alone	Total			
						A	B	T			$\frac{B}{A+C} \times \frac{100}{1}$
Richardson (1996) ¹⁷	621	? x=18.9	Initial ^a	Dentin	No	0	364	545	ND	ND	201.1 ^e
Weerheijm (1992) ⁹	123	17-20	WHO ^b	Dentin	No	37	461	578	ND	ND	394.0 ^f
Hopcraft (2005) ⁷	879	17-30	Initial ^a	Dentin	No	300	91	486	0.33 ^f	98.4 ^f	20.7-31.7 ^f
Galceran-Civera (2007) ³²	30	15-65	Initial ^c	Enamel and dentin	No	17	75	101	0.28 ^e	97.9 ^e	288.5 ^f
Eggertsson (2007) ²⁹	ND	15-?	ICDAS I ^d	Enamel and dentin	No	2150	3949	ND	ND	ND	Two-fold increase ^e

¹Cohen's Kappa agreement
²Observed percentage agreement on diseases and sound surfaces for both CE and RE
^aVisually apparent cavitation, discoloration showing through enamel or visual evidence of recurrent caries around a restoration.
^bCriteria derived from WHO with two major modifications (use of a probe as diagnostic aid on cases of doubt and addition of additional score (1) for presence of dentin caries that did not meet the criteria. Score 1 was considered sound).
^c(C1) clinical lesion in intact enamel, such as white spot with intact surfaces, (C2) lesion or small cavity, clinically detectable, confined to the enamel, (C3) caries lesion in dentin, detectable as present if any of the following signs were observed: evident cavitation, or pits and fissures strongly stained and extended with bottom softened, or pits, fissures and edges with enamel discoloured from lack of dentin support.
^dFilled surfaces were excluded.
^eAs reported on study.
^fValues obtained manually, non-reported on study.
ND Not possible to determine, due to lack of data.

Table 2. Summary of studies investigating the value of bitewing radiographs in the diagnosis of posterior proximal caries in permanent teeth.

Study (year)	N	Age	Diagnostic threshold		Histologic validation	Lesions detected			Kappa value ^A	Percentage of agreement ^B	Additional diagnostic yield (%)
			CE	RE		CE alone	RE alone	Total			
						A	B	T			$\frac{B}{A+C} \times \frac{100}{1}$
Bodmer (1939) ³³	51	18-50	Cavitation ^a	? ^a	-	-	-	-	ND	ND	-
Dunning (1946) ³⁴	100	men	? ^a	Dentin ^a	-	-	215	315	ND	ND	215.0 ^a
Barr (1950) ³⁵	162	18-30	? ^a	Initial ^a	No	66	801	1123	ND	ND	248.8 ^a
Hansen (1980) ³⁶	100	35	Cavitation ^a	Initial ^a	-	59	340	447	ND	ND	317.8 ^a
Stephens (1981) ³⁷	54	13-50	? ^a	Initial ^a	-	-	171	335	ND	ND	-
Richardson (1996) ¹⁷	634	? x=18.9	Initial ^b	Enamel and dentin	No	14	469	713	ND	ND	192.2 ^g
Poorterman (1999) ¹⁸	621	17-23	Enamel ^c	Enamel and dentin	No	55	1224	1372	0.11 ^f	89.5 ^f	827.0 ^g
Poorterman (2000) ¹³	96	25-34	Dentin ^d	Enamel and dentin	No	-	-	-	0.22 ^f	96 ^f	391 ^g
	96	35-54	Dentin ^d	Enamel and dentin	No	-	-	-	0.36 ^f	93 ^f	206 ^g
Hopcraft (2005) ⁷	879	17-30	Initial ^b	Enamel and dentin	No	17	242	324	0.31 ^f	98. ^f	295.1 ^g
Galcera-Civera (2007) ³²	30	15-65	Initial ^e	Enamel and dentin	No	17	75	101	0.18 ^g	94.4 ^g	288.5 ^f

^ACohen's Kappa agreement.
^BObserved percentage agreement on diseases and sound surfaces for both CE and RE.
^aAs presented in (Kidd EAM, Pitts NB. A reappraisal of the value of the bitewing radiograph in the diagnosis of posterior approximal caries. Br Dent J 1990;169:195-200.)¹²
^bVisually apparent cavitation, discoloration showing through enamel or visual evidence of recurrent caries around a restoration.
^cDecayed was scored when a lesion was present which expressed itself as a clearly undermined marginal crista or as a discontinuity of the enamel (Score 1).
^dEnamel lesions were not recorded, however they considered decayed when lesion was present that expressed itself as a clearly undermined marginal crista or as a discontinuity of the enamel.
^e(C1) clinical lesion in intact enamel, such as white spot with intact surfaces, (C2) lesion or small cavity, clinically detectable, confined to the enamel, (C3) caries lesion in dentin, detectable as present if any of the following signs were observed: evident cavitation, or pits and fissures strongly stained and extended with bottom softened, or pits, fissures and edges with enamel discoloured from lack of dentin support.
^fValues obtained manually, non-reported on study.
^gAs reported on study.
ND Not possible to determine, due to lack of data.

Table 3. Outline of the detection criteria used in the present study for the clinical and radiographic caries detection methods.

Clinical criteria	
S	Sound surface
P	Surface with pit and fissure sealant
C	Surface with crown
F	Surface with a direct restoration
D1, FD1, PD1, CD1	Surface with non-cavitated caries lesion (D1), non-cavitated caries lesion around restorations (FD1), non-cavitated caries lesion around pit and fissure sealants (PD1), and non-cavitated caries lesion around full-coverage crowns (CD1)
D2, FD2, PD2, CD2	Surface with cavitated caries lesion within enamel (D2), cavitated caries lesion within enamel around restorations (FD2), cavitated caries lesion within enamel around pit and fissure sealants (PD2), and cavitated caries lesion within enamel around full-coverage crowns (CD2)
D3, FD3, PD3, CD3	Surface with cavitated caries lesion into dentin (D3), cavitated caries lesion into dentin around restorations (FD3), cavitated caries lesion into dentin around pit and fissure sealants (PD3), and cavitated caries lesion into dentin around full-coverage crowns (CD3)
M	Missing (extraction, uneruption)
Y	Unable to score
Radiographic criteria	
0	Sound surface
C	Surface with crown
F	Surface with a direct restoration
1, F1, C1	Surface with a radiolucency compatible with caries lesion on the outer ½ of the enamel (1), surface with a radiolucency compatible with caries lesion on the outer ½ of enamel around restorations (F1), and surface with a radiolucency compatible with caries lesion on the outer ½ of enamel around full-coverage crowns (C1)
2, F2, C2	Surface with a radiolucency compatible with caries lesion on the inner ½ of the enamel (2), surface with a radiolucency compatible with caries lesion on the inner ½ of enamel around restorations (F2), and surface with a radiolucency compatible with caries lesion on the inner ½ of enamel around full-coverage crowns (C2)
3, F3, C3	Surface with a radiolucency compatible with caries lesion on the outer ½ of the dentin (3), surface with a radiolucency compatible with caries lesion on the outer ½ of dentin around restorations (F3), and surface with a radiolucency compatible with caries lesion on the outer ½ of dentin around full-coverage crowns (C3)
4, F4, C4	Surface with a radiolucency compatible with caries lesion on the inner ½ of the dentin (4), surface with a radiolucency compatible with caries lesion on the inner ½ of dentin around restorations (F4), and surface with a radiolucency compatible with caries lesion on the inner ½ of dentin around full-coverage crowns (C4)
M	Missing (extraction, uneruption)
Y	Unable to score (orthodontic appliances, overlapping teeth or film errors)

Table 4. Proposed crosstabulation between the clinical ICDAS-II modified clinical criteria and the radiographic criteria. Recoding of the criteria for final data analysis.

Tooth surface status	CE	RE	Recoding for simplified analysis
(Non-Disease)	S, F, C, P	0, F, C	0 (Non-Disease)
(Disease)	D1, D2,D3, FD1, FD2, FD3, PD1, PD2, PD3, CD1, CD2, CD3	1, 2, 3, 4, F1, F2, F3, F4, C1, C2, C3, C4	1 (Disease)
Missing	M	M	M
Not scored	Y	Y	M

Table 5. Total number of caries lesions detected by clinical examination and radiographic examination, stratified by type of surface (n=2415).

Surfaces	Caries lesions detected (Disease)			Percentage of agreement ^A	Kappa values ^B	95% confidence interval
	CE	RE	Total			
All	292	283	494	82.9	0.18	0.1324-0.2370
Occlusal	33	20	51	93.2	0.04	(-0.0580)-0.1429
Proximal	259	263	443	78.5	0.18	0.1182-0.2330
^A Observed percentage agreement on diseases and sound surfaces for both CE and RE ^B Cohen's Kappa agreement						

Table 6. Total number of caries lesions detected by clinical examination and radiographic examination stratified by type of surface. Calculations of the effects of adding radiographic analysis to the clinical analysis (diagnostic yield) by type of surface (n=2415).

Surfaces	Caries lesions detected (Disease)			Additional diagnostic yield	
	CE alone	RE alone	Both	Total	
	A	B	C	T	$\frac{B}{A+C} \times \frac{100}{1}$
All	211	202	81	494	69.2
Occlusal	31	18	2	51	54.6
Proximal	180	184	79	443	71.0

Figure 1. Modified criteria for proximal lesions by White and Pharaoh in accordance with Pitts⁴²


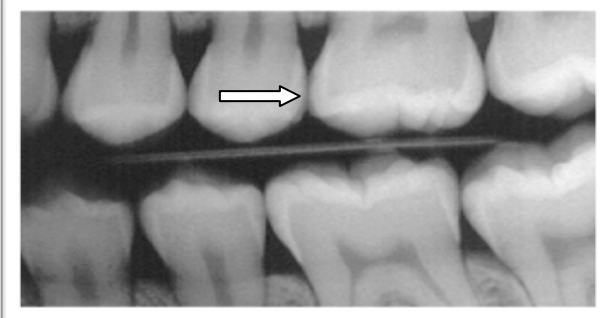

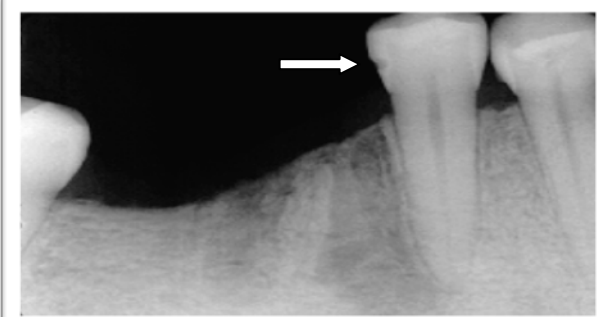


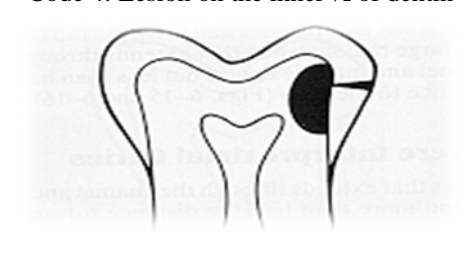
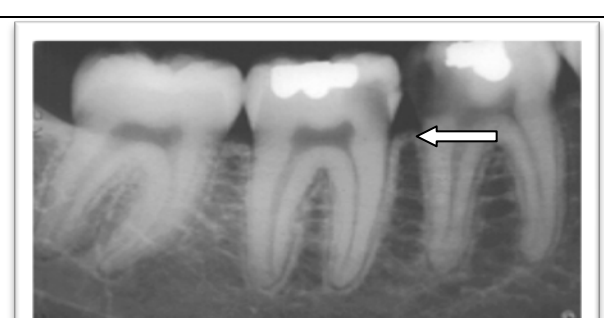
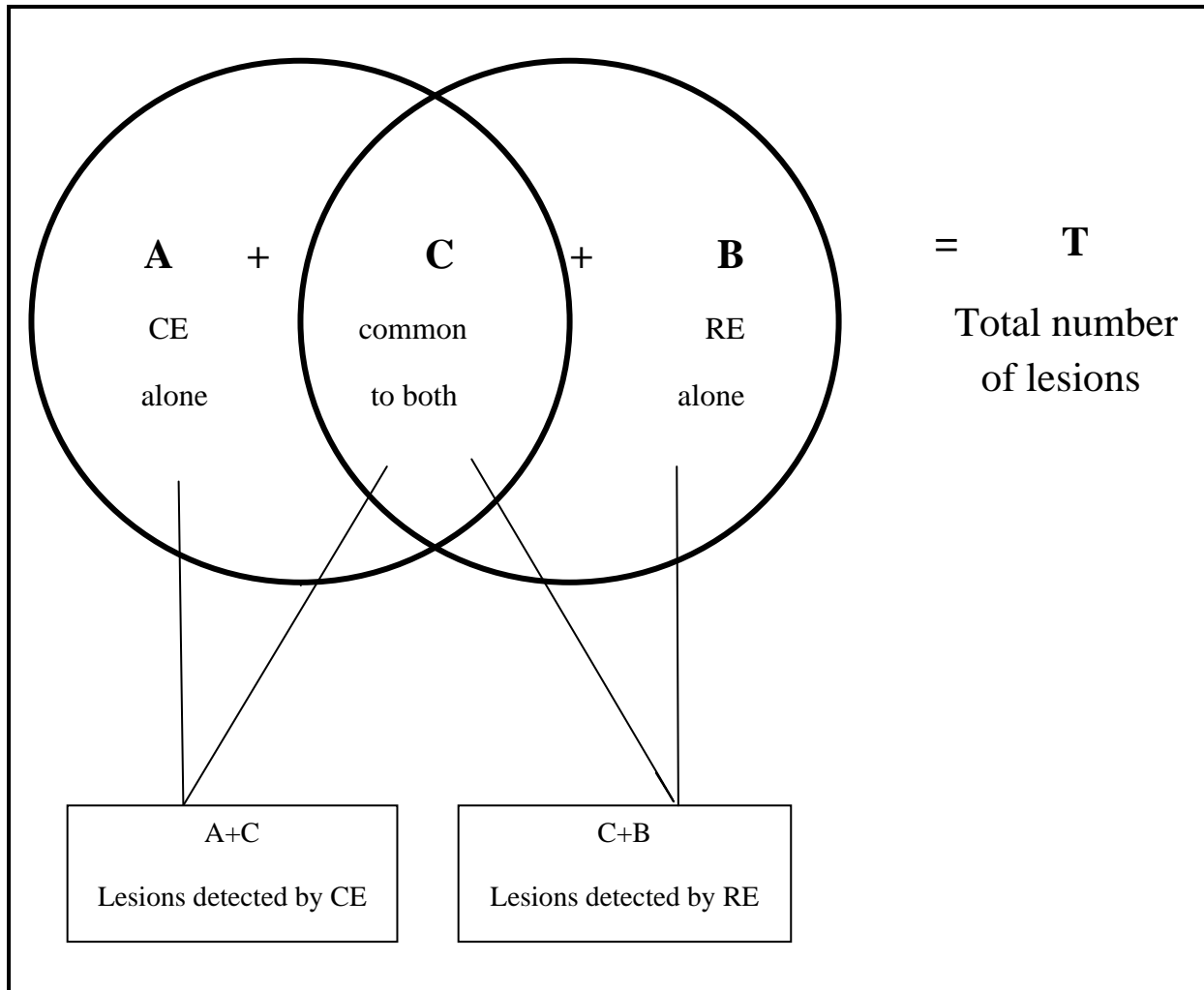
<p>Code 1: Lesion on the outer ½ of the enamel</p> 	
<p>Code 2: Lesion on the inner ½ of the enamel</p> 	
<p>Code 3: Lesion on the outer ½ of dentin</p> 	
<p>Code 4: Lesion on the inner ½ of dentin</p> 	

Figure 2. Relationship between CE and RE caries detection methods. Note that ‘C’ represents lesions common to both techniques. Total number of lesions is derived by adding A+B+C. Total numbers of lesions cannot be derived by adding (A+C) + (B+C) as this result in double counting of C lesions common to both detection methods¹²



Appendix. Radiographic data collection form

X-ACT Ancillary Study X-ray Data

Office Use Only

Participant ID: _ _ _ _ _

Cx Exam Date: _ _ / _ _ / _ _

Name Code: _ _ _ _ _

BW Date: _ _ / _ _ / _ _

EPR: _ _ _ _ _

Examiner: FA / MR

Gender: M/F **Participant age:** ____

MAXILLARY RIGHT QUADRANT

Surface	Tooth #2	Tooth #3	Tooth #4	Tooth #5
Occlusal				
Mesial				
Distal				

MAXILLARY LEFT QUADRANT

Surface	Tooth #12	Tooth #13	Tooth #14	Tooth #15
Occlusal				
Mesial				
Distal				

MANDIBULAR LEFT QUADRANT

Surface	Tooth #18	Tooth #19	Tooth #20	Tooth #21
Occlusal				
Mesial				
Distal				

MANDIBULAR RIGHT QUADRANT

Surface	Tooth #28	Tooth #29	Tooth #30	Tooth #31
Occlusal				
Mesial				
Distal				

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